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AIDING THE DECISION MAKER: PERCEPTUAL AND COGNITIVE ISSUES AT THE HUMAN-MACHINE INTERFACE

James D. Walrath

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Advances in weapon and sensor technologies have given rise to very complex military systems. The soldier-machine interface, typical of such systems, is often characterized by elevated task loadings and speed stress. These conditions can combine to produce increased operator errors and degraded decision-making performance. This report acknowledges these operator performance problems and provides a general review of the human judgment and decision-making literature (specifically focusing on perceptual and attentional mechanisms). An abridged history of the psychological study of human decision making is provided to illuminate the domain, and four methods are discussed for improving the performance of systems that suffer because of poor human judgment and decision making. A special plea is made to consider aiding harassed decision makers by paying careful attention to principles of human perception and attention, because these mechanisms form the foundation of our ability to acquire relevant and timely problem data. Keywords.

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AIDING THE DECISION MAKER: PERCEPTUAL AND COGNITIVE ISSUES AT THE HUMAN-MACHINE INTERFACE

INTRODUCTION

> We can make a machine that will do almost anything, given enough time and engineers. But man has limits to his development as far as we can see it. . . . Machines that demand superhuman performance will fail, and jobs that push man beyond the limits of his skill, speed, sensitivity and endurance will not be done. We are now reaching the point where, because of our human limitations, better and better equipment does not necessarily insure better and better performance (Chapanis, Gardner, & Morgan, 1949, p. 7).

Four decades have passed since Chapanis et al. warned about machines and jobs that human operators would find unmanageable. The intervening years have seen immense achievements in science and technology; yet, these concerns remain as valid today as they were in 1949. If anything, technology has made it easier to develop systems that exceed operator limitations, especially cognitive limitations. Modern military systems are no exception. They have achieved levels of complexity, sophistication, and performance which place unprecedented information processing demands on crews (Barnett, Stokes, Wickens, Davis, Rosenblum, & Hyman, 1987; Boyne, 1986; Porubcansky, 1985; Taylor & Munson, 1977).

Sophisticated technology has brought about an increasingly complex decision environment for the operator. The speed, accuracy, and mobility of modern military weapons leave little time to consider options. Stress resulting from the time course of events is further aggravated by an accompanying proliferation of sensor technology. Crews have more stimuli to attend to (increased task loading) and less time to allocate to them (increased speed stress). Ample evidence exists to indicate that these effects increase operator errors and degrade decision performance (e.g., Conrad, 1955; Goldstein & Dorfman, 1978; Mackworth & Mackworth, 1958; Wickens, 1984; Wright, 1974). A contemporary example is the July, 1988, downing of Iran Air Flight 655 by the USS *Vincennes*. Misidentifying the approaching commercial airliner as a hostile Iranian F-14 fighter, the *Vincennes* launched two MS-2 missiles, resulting in the loss of the aircraft and all 290 passengers aboard.

Degradation in overall performance of dynamic systems can result from a number of factors, some of which relate to the machine, and some to the human operator. In the case of the *Vincennes*, the Navy concluded that while the ship's high technology systems provided the crew with accurate information, human perception, processing, and communication of this information was flawed. If the system suffers because of poor human performance, the cause often rests with faulty judgments or decisions. This circumstance forms the basis of this report. Specifically, our pursuit of technology has resulted in the creation of person-machine systems that equal, and frequently exceed, human information processing and decision making limits. Technology, having given rise to these unwelcome effects, is now being called upon to negate them.

Objectives

The objectives of this report are to

1. emphasize the growing complexity of decision making tasks inherent in many of our modern military systems;

2. provide an abridged account of the psychological study of human judgment and decision making; and

3. discuss the relative merits of four methods for aiding the harassed decision maker.

A Brief History of the Study of Human Decision Making

Scientific psychology did not emerge as a discipline until the latter part of the 19th century. The study of human decision making, unfortunately, has an even shorter history. Early interest in the function of consciousness (e.g., decision making) by such men as William James was displaced in the 1920s by a reflexive acceptance of John Watson's theory of Behaviorism. Watson insisted that any event that could not be publicly observed was not proper subject matter for scientific inquiry. Consequently, interest in cognitive functions waned. It was not until World War II that psychology, as a science, rediscovered the importance of developing models of cognitive processes. In particular, the 1980s have seen increased interest in human decision making because the growing sophistication of the person-machine interface is becoming, by degrees, an interaction between two cognitive systems.

Despite the considerable work that has been done, there is still no universally accepted definition of the human decision making process. This lack of agreement arises from the fact that we cannot directly observe the making of a decision. It is a private, subjective experience, and its presence and processes must therefore be inferred from observable behavior. Logically, decision making must at least be operationally defined before it can be discussed. In satisfaction of this requirement, a decision will be said to have occurred when an operator selects a course of action from among a number of possible alternatives. Further, the time taken to make the selection must be relatively long (to distinguish a decision from a reflex), and the correct option must not be obvious (i.e., the rational decision maker faces a true choice).

While the cognitive process of decision making remains a matter for enlightened speculation, the primary dimensions that describe a decision problem and are external to the operator are quite clear. Foremost among these parameters is the type of decision task at hand. A decision may require a choice of one option from among several possibilities, or it may require either the diagnosis of the present system state or the prediction of a future system state. No matter the type of decision required, the level of difficulty increases with increasing numbers of stimulus and response options. The frequency of incoming stimuli is another significant component of decision making. Operators are most adept at processing simultaneous (parallel) sensory input if it is received over the visual channel, because it is spatially rather than temporally configured. Regardless of the sensory channel used, difficulty increases with increasing stimulus frequency.

Finally, the cumulative stress level (resulting from the operating environment, task saturation, task criticality, etc.) is clearly a limiting factor of decision-making performance.

Theoretical approaches to the decision making process tend to polarize toward either of two positions, normative or descriptive. Normative theories (dominant in the 1950s and 1960s) originate from economics, mathematical statistics, and operations research. These theories describe how behavior should proceed to realize consistent optimal outcomes. Primarily Bayesian in nature, they make assumptions about human decision making that are difficult to substantiate. For example, the Bayesian framework assumes (a) conditional independence of evidence; (b) perfectly reliable data; and (c) well-defined sample spaces. These are not characteristic of the natural environment in which decision makers function. Einhorn and Hogarth (1981, p. 61) make the point that "normative models gain their generality and power by ignoring content in favor of structure and thus treat problems out of context." While normative theories are no longer generally regarded as highly descriptive of the way people make decisions, they can be useful in defining the upper performance limits against which actual behavior can be compared.

By the early 1970s, psychology was formulating a new genre of decision theory, a descriptive theory, based in cognitive psychology and colored by an appreciation for the roles of attention and memory in the decision process. Central to any interpretation of a descriptive theory of decision making is the observation that many contemporary systems are characterized by multiple complex tasks requiring human information-processing capacities exceeding the operator's resources. Because people are so adaptive, operators cope with these tasks by adopting strategies that reduce cognitive processing to manageable levels. Descriptive decision theories recognize the usefulness of these heuristic methods ("rules of thumb") in that without them many complex tasks would be impossible to perform. Unfortunately, using heuristic methods to simplify decision making also introduces considerable bias in the process (Tversky & Kahneman, 1974; Slovic, Fischoff, & Lichtenstein, 1977; Einhorn & Hogarth, 1981; Kahneman, Slovic, & Tversky, 1982).

While a number of biases have been observed, the three that are often sighted as the most compelling are representativeness, availability, and anchoring (Tversky & Kahneman, 1974). Representativeness refers to our inclination to view objects or events as belonging to specific classes or processes based on the degree to which the former "looks like" the latter. In the process, we tend to ignore such salient cues as prior odds, sample size, and regression toward the mean. The ease with which we can recall a similar scenario also influences our judgment (i.e., we will not consider an hypothesis we cannot recall). Known as availability, this heuristic method subjects the decision maker to predictable errors caused by illusionary correlations, inefficient memory search strategies, and biases because of the familiarity and salience of past events. Anchoring refers to one's tendency to assign inordinate diagnostic importance to early stimulus evidence. Lead stimuli thus establish the anchor points for our perceptions, while later evidence only shifts these anchors slightly in one direction or the other. Anchoring is closely tied to the human attentional process. When we "pay attention" to something, we mean that we are being perceptually selective. The portion of our sensory world that we choose to bring into consciousness is often driven by the prominent nature of the stimuli. Consequently, the most salient stimulus is likely to be the one attended to first, and therefore the one that exerts the most influence on our perception of the situation.

The classical view of decision making implies a parallel process in which a number of options are generated and evaluated as a group, and one option is then selected for implementation. The literature seems to indicate that this model may be somewhat representative of the novice decision maker, but much less descriptive of the expert. In a 2-year investigation of decision making among novice and expert fire ground commanders, Calderwood (1988) determined that the expert was three times more likely than the novice to report the use of a serial approach to decision making. Using this method, a single hypothesis was generated and then implemented or rejected on the basis of a rapid assessment of its forecasted results. Mental imagery was the key to this method in that the decision maker would create a mental model of the problem using observed cues and the commander's knowledge and experience of similar events. Based on this model, the commander would generate a plan of action and a prediction about what would happen if the plan were implemented. This is rather like creating a mental screen play, assigning actors to parts, and then fast-forwarding through the script to watch the final act. In contrast, the novice commanders reported using a concurrent evaluation of multiple options, employing a rule-based cost benefit analysis (the classical model).

In concluding this section, it is clear that there is much to learn about how humans make decisions. Even so, several tantalizing pieces of the puzzle are known. Cognitive resources are limited and sensory input is unlimited. Heuristic methods resolve this conflict by simplifying cognitive processing. Unfortunately, their use can result in biases that keep people from achieving optimum decision making performance (as described by normative theories). Two of the three prominent biases, representativeness and availability, are clearly linked to cumulative experience and memory functions. The third, anchoring, speaks to the influence of attentional processes on decision making. Finally, it seems that expert decision makers use mental imagery to solve problems, while the novice must rely on the more classical, rule-based methodology.

Vigorous work toward applying knowledge gained from the study of human decision making has led to the creation of a new scientific field of endeavor known as decision aiding. The following section introduces some of the methods used in supporting the human decision maker.

Methodologies for Improved Decision Making

Several methods are available for enhancing system performance given that the system suffers because of poor human judgment and decision making. These include the application of cybernetics, reallocation of functions, enhanced training, and refinement of the human-machine interface. These methodologies vary both in their relevance to a particular situation and in their technical intricacy, from highly complex (cybernetics) to comparatively simple (training). Further, each method approaches the problem from a different perspective. Because of this diversity, a brief discussion of each method is helpful in understanding the broad field of decision aiding.

Cybernetic systems

"The traditional dream of traditional engineers has been to solve the problem of human error by eliminating its source" (Wiener & Curry, 1980, p. 996). This is state-of-the-art in many computer-aided manufacturing applications characterized by simple inspection tasks or object

manipulations. However, expansion of this technology to include the control of complex dynamic systems embodying high levels of uncertainty (thus requiring judgments when events cannot be completely defined) is more state-of-anticipation than state-of-the-art. Even when technically feasible, a number of moral and ethical questions regarding the use of cybernetic systems will have to be resolved before implementation. For example, what is the likelihood of fielding a medical system that makes life and death decisions without human review? While research continues to address these high levels of problem sophistication, real needs exist at lower levels. The remaining methodologies exist to serve this need, albeit each from its own perspective.

Function reallocation

A second, less severe, tactic for mitigating decision errors in person-machine systems is to reallocate functions. In any complex system, some functions must be performed by equipment (in air defense, for example, the weapon must disable the enemy aircraft). Other functions are performed by the human operator or by an amalgamation of personnel and machinery. The basic premise in reallocating functions is that system performance can be enhanced by identifying those functions that are problematic for the human decision maker and then transferring the responsibility for them to the machine. These reallocations are typically driven by evidence of non-optimal human decision behavior (Einhorn, 1980; Hogarth, 1987; Kahneman, Slovic, & Tversky, 1982; Tversky & Kahneman, 1974). This approach has become popular because it seems completely sensible from an engineering perspective. The decision aiding literature reflects this focus as can be noted from the large number of reports dealing with the design of autonomous (stand alone) systems that provide computer-assisted planning functions or provide solutions to domain-specific problems (e.g., Freedman & Malowany, 1988; Steeb & Johnston 1981; McIntyre & Adelman, 1985; Charny, Hornsby & Sheridan, 1987; Ulvila & Thompson, 1988; Coleman, 1986; Snell, 1988; Casper, Shively, & Hart, 1987).

Aiding the human decision maker by reallocating functions to machine systems can, however, create new problems. For example, as systems become more automated, the role of the human operator changes from active controller to system supervisor. This shift in province brings about a change in the type of attention required of the operator. As an active controller, the operator was required to divide his attention among many competing stimuli. The supervisor's role, on the other hand, is more likely to require sustained attention (vigilance). Considerable effort has been expended in studying the effects of sustained attention on human performance, and an excellent overview of this work appears in the chapter on vigilance in Parasuraman (1986). While a detailed discussion of the topic lies outside the scope of this work, two facts that are particularly relevant emerge from the literature. First, as time on task lengthens beyond about 30 minutes, there is less likelihood of an operator detecting a weak stimulus (characterized by low intensity, brief duration, or both). Second, when a stimulus is detected, the time required by the operator to react (response latency) is uncharacteristically long. Even though a supervisory operator makes fewer decisions per unit of time than does an active controller, the consequence of each decision is generally more grave because it impacts the system at a global, rather than local, level. Under these conditions, the effects of degraded signal detection performance and increased response latencies become increasingly serious.

Another concern surrounding the reallocation of functions arises because the modified system is not always recognized as a new system. Senders (1988, p. 88) has noted the following:

> There's a natural tendency to believe that if a system is redesigned to eliminate error-inducing features, then the number and frequency of errors will decrease. That should indeed be the case, <u>but only with respect to those errors which had previously occurred</u>. A redesigned system is not the old system minus its defective features: it is a <u>new system</u>. The changes which are implemented will provide opportunities for different errors to occur.

Operator complacency is yet another issue. Regardless of the degree of automation, some incidents (e.g., falling asleep at the controls of a nuclear power plant) are clearly attributable to deliberate inattentiveness. In other instances, errors once attributed to complacency may have less condemning determinants. For many systems, the result of applying advanced technology has been to reduce the intensity of interaction between people and machines. For example, many new cars bristle with technology aimed at reducing the level of interaction between car and driver. Headlights are turned on and off, even dimmed or brightened, depending on the level of ambient light. Thermostatic control of the heater and air conditioner eliminates the need for attention to the interior thermal environment. Cruise control eliminates the need for continuous manual control of the engine throttle. Even the car's radio is designed to lessen human interaction by automatically scanning all the available broadcast radio frequencies. Significantly, for the human operator, these systems give rise to work load levels that are relatively moderate and stable across time, but which may also intensify abruptly when the automated system malfunctions or an emergent situations occurs. Obviously, work load can also decrease rapidly when the emergency passes or the automated system again becomes functional. Thus, two distinct variations in work load are possible: abrupt increases and equally sudden decreases.

It is natural for concern to focus on the effects of unexpected jumps in work load. Dramatic examples attract public attention, such as the 30,000-foot plunge of a China Airlines 747 following deactivation of the autopilot ("High Tech," 1989). The sudden decline in work load, however, has received less attention even though its effects may be as potent. Perhaps this is true because we expect high levels of work load to be detrimental, while citing a decrease in work load as the reason for poor performance is counter-intuitive. However, real world examples do exist in support of the phenomenon. Allnutt (1982) references an occasion when a railroad engineer allowed his locomotive to pass through a red signal during a period of low work load which had been preceded by a sustained period of very high load levels.

The concept has also received experimental validation. In a series of experiments by Matthews (1986), sudden decreases in work load were evaluated. In these experiments, subjects who were trying to detect target signals comprised of numeric strings of simple arithmetic expressions (e.g., 24+14 < 27), monitored a display. These target signals were presented along with non-target (noise) signals made to appear similar but with no arithmetic meaning (e.g., 26+#1 > T$). The signal and noise stimuli were organized in a three-column by four-row matrix presented to the subject via a CRT display. Work load was varied by displaying one, two, three, or all four rows of stimuli. The subject first determined if a target signal was present (half

of the trials contained a target signal). If a signal was detected, its position in the stimulus matrix was indicated. Subsequent to detecting a signal, the subject evaluated its arithmetic correctness. The number of target locations and target rates were varied. Performance by experimental subjects was contrasted with that of control subjects who received stable work load levels throughout the experimental session. Results indicated that sudden decrements in work load level caused significantly lower decision making accuracy than did sudden increases. Matthews (1986) suggests that this effect (hysteresis) may occur because high load conditions force a change in operator strategy which persists after the work load level drops, even though it is a non-adaptive strategy at low loadings. Specifically, when the operator must respond at high rates, a speed-accuracy trade-off occurs with accuracy giving way to speed. When work load drops, the subject continues responding with the same urgency even though accuracy suffers unnecessarily. This temporal variability of work load is characteristic of highly automated systems. Clearly, the load history of an operator is an important determinant of performance, and ill-fated operators who are accused of complacency may be less culpable than previously thought.

Another concern associated with transferring functions from operator to machine involves the perception of control (i.e., the degree to which an operator feels he or she is in control of his or her destiny). Operator performance can suffer whenever the machine, not the person, is perceived as dominant in system control (Woods, 1986). Past research by Perlmuter and Monty (1973, 1977, 1982) has demonstrated that providing a subject with some degree of choice in the task environment enhances learning, proficiency, response times, and even the ability to recognize and discriminate information. Further, these facilitatory effects endure for a considerable time (Monty & Perlmuter, 1975) and can generalize to secondary tasks if they are temporally adjacent to the primary task.

Certain warnings apply to the use of choice as a method of improving performance. Perlmuter and Monty (1977) found that the measure of choice allowed is not as important as when it is offered. To be maximally affected, the subject must experience the choice at the beginning of a task. Further, the authors note that allowing choice opens the possibility for frustration, and frustration has serious performance effects. Subjects who were asked to perform tasks over which they had no control showed better learning rates and overall proficiency than subjects who were allowed to make choices but were then asked to perform without their choices being implemented.

The larger point is that the degree of successful interaction between human and machine is not predicated on a single factor. That is why poor performance cannot invariably be abated by automation. Calderwood (1988, p. 39) has pointed out that

> There is always a danger in trying to isolate a single element in a complex task. The tendency is to inflate the importance of whatever variable is being studied and to miss the importance of how all the elements interact.

Training.

A third approach to reducing decision errors in human-machine systems is to improve training. This might be accomplished by improving

training quality, quantity, or both. Viewing decision making from the larger perspective of human performance provides insight about ways that training can affect judgment and decision making.

A cost is always incurred when a person interacts with a system. These costs fall into two categories, perceptual motor loads or central processing loads (Wickens, 1984). Both can have consequences for the decision maker, but the effect of increased central processing loads is of concern here. Even though many factors can affect task performance (ability to learn, fatigue, motivation, etc.), operator overload is commonly identified as a primary contributor to poor human performance in complex systems (Tolcott & Holt, 1987). This overload can be one of two types, quantitative or qualitative. Quantitative overload can be thought of as resulting from too much work to accomplish in the allotted time. Qualitative overload results, even if enough time is available, when the task is simply too difficult. For the operator experiencing quantitative overload, training will enhance performance only if it results in the acquisition of strategies which bring about an enhanced economy of processing, thus freeing additional resources for the tasks at hand. Improved training may benefit an operator experiencing qualitative overload if it can bestow the skills and knowledge necessary for successful task performance. Increasing training time will have little effect on either operator, unless (a) the initial training was too brief to allow for the proper assimilation of information or (b) training time is expanded to epic proportions in an effort to make some responses "automatic."

Tasks that require physical or cognitive powers beyond the limits of an operator will not be performed well regardless of training strategy. For example, consider the situation in which an operator must make decisions based on the precise reading of a circular dial-type indicator. Further, imagine that the scale graduation marks subtend a visual angle of .83 minute when viewed from the operator's position. An operator with a visual acuity worse than 20/17 will be unable to read the indicator, and will therefore be unable to make rational decisions. No amount of training will alter this outcome; the task requirements simply exceed the operator's ability.

Manpower and personnel costs associated with increased training time are such that this solution is very often difficult to justify. Improving the quality of training is always a good idea but it, too, must survive cost benefit analysis. However, the most decided disadvantage in enlisting a training solution to overcome decision errors lies not with the cost, but with the fact that this approach often denies the true locus of the problem. According to Roscoe (1987, p. 4), "It has always been easy to dismiss design deficiencies as training problems because people are so adaptable."

Refining the human-machine interface.

There is little question about the future of automation. On the one hand we see mounting pressure for safer, more reliable, and more economical systems; on the other, the requirement for smaller crew sizes. At present, the simultaneous satisfaction of these goals can be realized only with the judicious application of automation. Current efforts toward this end have resulted in the reduction of manual tasks, but reports also indicate that "the equipment does not appear to live up to its expectations in reducing crew work load" (Wiener, 1988, p. 434). Clearly, prevailing approaches to operator aiding have, in many cases, missed the mark. Given

that equipment usually performs as advertised and that personnel are competent, part of the problem may lie at the gulf between operator and machine.

To achieve maximum system performance, the interface between human and machine must serve to couple the two together as closely as possible. Designing systems to meet this goal requires increased sensitivity to human limitations in sensory, perceptual, and cognitive abilities. In applying this philosophy, the best return on investment usually comes from consideration of display design, because system engineers often misinterpret the role of displays. While the operational purpose of a display is to convey information to the user, McCormick reminds us (McCormick & Sanders, 1982) that a display is actually just an ordering of stimuli intended to be meaningful to the user. "Thus, when we discuss the organization of information, this is really a euphemistic way of referring to the organization of stimuli..." (McCormick & Sanders, 1982, p.45). Viewed from this perspective it is clear that display design should be driven not, as it almost always is, by the push of technology but by the application of empirically derived principles of human perception and cognition. Designs that enhance the perceptibility[1] of a display will ultimately result in a reduction of operator mental work load, benefiting the user by freeing cognitive resource for other tasks.

CONCLUSIONS

There is little doubt that progress will (and should) continue toward the reallocation of some human tasks to autonomous machine aids. Much of the effort in this direction is concentrated in an attempt to mature the relatively new fields of artificial intelligence and expert systems. The application of these technologies to human judgment and decision making has resulted in the development of new fields of technical endeavor known as decision aids or decision support systems. As their names imply, they were conceived as support systems for human decision makers. Often, however, these systems replace, rather than support, human judgment (Seilheimer, 1988; Cohen, 1987). Whether these fields of endeavor will deliver the tremendous benefits expected of them remains uncertain. In a review of five autonomous decision aids for military environments, Barnes (1980, p. 60) reported that "...there is little evidence that these aids would be useful in an actual operational environment." Some of the most respected researchers in the area of human judgment and decision making have also expressed doubts. Robyn Dawes (1987), of Carnegie-Mellon University, has written:

> I do not claim expertise in the field of constructing decision aids ("expert systems") meant merely to "simulate" whatever the decision maker does, or however it is that people think. I do, however, believe that there is a basic problem with such an approach. It assumes that decision and thought follow single principles, but we do not decide or think in just one way. Russell, for example, understood the importance of base rates long before the field of "Bayesian" decision making emerged. Others did not. Nor is it true that a "superior" person will always make

[1]Following Easterby (1967, p. 200), perceptibility is defined as "...the ease with which one can assign meaning to a particular portion of a display."

good decisions, and particularly not somebody whose alleged superiority is based on "expertise," which is essentially a socially defined variable. Thus, even attempts to simulate the decision and thinking process of a single individual picked as unusually good will not necessarily aid anyone, even that individual.

These negative attitudes regarding autonomous decision aids are partly generated by a general lack of user acceptance (Tolcott & Holt, 1987). While the basis for this lack of user enthusiasm has not been definitively established, certain hypotheses have been suggested, the most basic being people's disinclination to acknowledge their own judgmental deficiencies (Einhorn & Hogarth, 1978).

Other explanations center about the fact that the plans or problem solutions generated by autonomous decision aids must still be accepted or rejected by the human user. Woods (1986) has pointed out that very little is known regarding how adept people are at discriminating between correct and incorrect machine solutions. Further, he raises the question about whether an operator really has the authority to countermand machine output. Regardless of these concerns, the fact remains that while the user has little or nothing to do with solution generation, he or she remains solely responsible for the consequences. This is quite naturally viewed as a disincentive by most users.

Additional difficulties with the acceptance of autonomous decision aids may arise from the fact that there are many different cognitive styles, perhaps as many as there are individuals (Mason & Mitroff, 1973). Further, there is nothing to suggest that any one individual always makes use of a single cognitive strategy. This uniqueness presents a formidable obstacle in the design of autonomous decision aids. (E.g., which style should the aid employ for a given user and set of circumstances to provide the close cognitive coupling necessary for optimal performance?) Decision aids employing excessively divergent strategies (in relation to the user's) can result in what Woods (1984) has called the "getting lost" and the "keyhole" phenomena. The getting lost phenomenon is characterized by a user's lack of understanding of system relationships, causing difficulty in deciding what to do or look for next within the system. The keyhole phenomenon refers to degraded user information extraction resulting from serial data presentation when parallel presentation is expected.

In working to overcome the several difficulties associated with autonomous decision aids, one should not lose sight of the opportunity afforded by aiding the decision maker at more basic levels. For example, regularities known as the visual constancies persist within and between people. Epstein and Park (1963) theorized that there are certain processing rules for the visual system that provide constancy in the perception of visual stimuli. The commonality of these visual phenomena suggests a promising focus for the design of decision aids that assist the user by enhancing the perceptibility of displayed information. Returning to his review (Barnes, 1980, p. 60) of decision aids for military environments, Barnes reported that "...some of the aids enhanced information-gathering by using optimal (display) formating [sic] techniques. This helped the operator in problem structuring, since the displays encourage the operator to eliminate obviously poor choices."

The mechanisms of human perception and attention, which form the foundation for our ability to acquire relevant and timely problem data, may be facilitated in several ways:

1. People are essentially analog thinkers. Accordingly, visual displays should present information in a relative, rather than absolute, format whenever possible. This is not to suggest that all, or even any, absolute displays should be eliminated. The point is simply that information displayed in a relative format allows for the integration of complex, multidimensional stimuli in a way that encourages parallel processing of the displayed information (Walrath, 1989).

2. Analogical representations can provide substantial savings of cognitive resources. This accrues from reduced memory and computational loads because the analogical display acts as external memory and facilitates memory referencing and retrieval (Woods, 1986).

3. In tasks requiring spatial orientation, as in weapons aiming and guidance, it is appropriate to consider the capacity of the peripheral visual channel (as opposed to the foveal channel). According to Leibowitz (1986, p. 605), "Although many spatial orientation functions could be carried out with central vision, it is functionally more efficient to utilize the peripheral fields for spatial orientation so as to free central vision for those tasks for which it is uniquely specialized." Leibowitz's comments are particularly significant when viewed in terms of the design of visual displays for weapon orientation. The reflexive nature of peripheral field spatial orientation points to the automatic processing of this type of information.

4. The recent history of a system should be readily available to its operator because people tend to reach decisions about the near future based on antecedent observations. The large, positive correlation between adjacent regions in time and space has not gone unnoticed by mankind, and is at the root of our compunction to see events as causal in nature (Moray, 1980). Reflecting again upon the USS *Vincennes* incident, a tragic loss of life might have been prevented if the radar display provided target altitude history to its distracted operator who wrongly interpreted the contact to be in a descending (hostile) flight path.

The goal in applying these principles to system design is to aid the human's decision process by enhancing his or her ability to focus attention on those elements of the problem domain that are most relevant. The U.S. Army Human Engineering Laboratory's Aviation and Air Defense Division will use these design considerations in the development and evaluation of visual displays for the Forward Area Air Defense (FAAD) system of systems. Specifically, the gunner's optical sight suggested for use in the line-of-sight rear FAAD weapon system will be the subject of experimentation aimed at improving the perceptibility of this information display. A display, which is envisioned as being common to all FAAD battalion nodes (i.e., the integrated weapons system display), will receive similar experimental efforts. These experiments will provide empirical data regarding human performance issues and will also help answer application feasibility questions.

REFERENCES

Allnutt, M. (1982). Human factors: Basic principles. In R. Hurst and L. Hurst (Eds.), Pilot Error (pp. 1-22). London: Granada.

Barnes, M. (1980). Review of Five Military Decision Aids. (pp.1-63). (Dept. of the Navy Report No. NWC/TP/6171). Naval Weapons Center: China Lake, CA. (DTIC No. AD-A085772).

Barnett, B., Stokes, A., Wickens, C., Davis, T., Rosenblum, R., & Hyman, F. (1987). A componential analysis of pilot decision-making. In Proceedings of the Human Factors Society 31st Annual Meeting (pp. 842-846). Santa Monica, CA: Human Factors Society.

Boyne, W. J. (1986). The Leading Edge. New York: Stewart, Tabori and Chang, Incorporated.

Calderwood, R. (1988). A view from the outside. Fire Command, 8, 34-40.

Casper, P., Shively, R., & Hart, S. (1987). Decision support for work load assessment: Introducing WC FIELDE. Proceedings of the Human Factors Society 31st Annual Meeting (pp 72-76). Santa Monica, CA: Human Factors Society.

Chapanis, A., Gardner, W., & Morgan, C. (1949). Applied experimental psychology: Human factors in engineering design. New York: Wiley.

Charny, L., Hornsby, M., & Sheridan, T. (1987). An interactive multi-objective decision-aiding system for tactical mission planning. Proceedings of the Human Factors Society 31st Annual Meeting (pp. 432-436). Santa Monica, CA: Human Factors Society.

Cohen, M. (1987). When the worst case is best: Mental models, uncertainty, and decision aids. In Tolcott & Holt (Ed.), Impact and Potential of Decision Research on Decision Aiding. (pp.35-37). (Dept. of the Navy Grant No. N00014-87-G-0146). Washington, DC: American Psychological Association. (DTIC No. AD-A192 276).

Coleman, J. (1986). Penetration analysis aids for the TAF mission planning system. Proceedings of the Fourth Annual Workshop on Command and Control Decision Aiding (pp. E1-E17). Dayton, OH: Armstrong Aerospace Medical Research Laboratory.

Conrad, R. (1955). Some effects of performance in perceptual load. Journal of Experimental Psychology, 49, 315-322.

Dawes, R. (1987). Rationality in deciding how to decide. In Tolcott & Holt (Ed.), Impact and Potential of Decision Research on Decision Aiding. (pp.19-21). (Dept. of the Navy Grant No. N00014-87-G-0146). Washington, DC: American Psychological Association. (DTIC No. AD-A192 276).

Easterby, R. (1967). Perceptual organization in static displays for man/machine systems. Ergonomics, 10, 195-205.

Einhorn, H. (1980). Learning from experience and suboptimal rules in decision making. In T. Wallsten (ed.), Cognitive Processes in Choice and Decision Behavior. Hillsdale, NJ: Lawrence Erlbaum.

Einhorn, H., & Hogarth, R. (1978). Confidence in judgment: Persistence of the illusion of validity. Psychological Review, 85, 395-416.

Einhorn, H., & Hogarth, R. (1981). Behavioral decision theory: Processes of judgment and choice. Annual Review of Psychology, 32, 53-88.

Epstein, W., & Park, J. (1963). Shape constancy: Functional relationships and theoretical formulations. Psychological Bulletin, 62, 180-196.

Freedman, P., & Malowany, A. (1988). SAGE: A decision support system for the sequencing of operations within a robotic workcell. Decision Support Systems, 4, 329-343.

Goldstein, I., & Dorfman, O. (1978). Speed and load stress as determinants of performance in a time sharing task. Human Factors, 20, 603-609.

High tech and human error above the clouds. (1989, January). U.S. News & World Report, p.8.

Hogarth, R. (1987). Judgment and Choice. New York: John Wiley and Sons.

Kahneman, D., Slovic, P., & Tversky, A. (Eds.), (1982). Judgment Under Uncertainty: Heuristics and Biases. New York: Cambridge University Press.

Leibowitz, H. (1986). Recent advances in our understanding of peripheral vision and some implications. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 605-607). Santa Monica, CA: Human Factors Society.

Mackworth, N. H., & Mackworth, J. F. (1958). Visual search for successive decisions. British Journal of Psychology, 49, 210-221.

Mason, R., & Mitroff, I. (1973). A program for research on management information systems. Management Science, 19, 475-485.

Matthews, M. (1986). The influence of visual work load history on visual performance. Human Factors, 28(6), 623-632.

McCormick, E., & Sanders, M. (1982). Human Factors in Engineering and Design (5th ed.). New York: McGraw-Hill Book Co.

McIntyre, J., & Adelman, L. (1985). Senior Battle Staff Decision Aids. (pp. 1-120). (Dept. of the Air Force Contract No. F30602-83-C-0154). Griffiss AFB: New York. (DTIC No. AD-B105 980L).

Monty, R., & Perlmuter, L. (1975). Persistence of the effects of choice on paired-associate learning. Memory & Cognition, 3, 183-187.

Moray, N. (1980). Human information processing and supervisory control. (pp. 1-73). (Dept. of the Navy Grant No. N00014-77-C-0256). Office of Naval Research: Arlington, VA. (DTIC No. AD-A092840).

Parasuraman, R. (1986). Vigilance, monitoring, and search. In K. Boff, L. Kaufman, and J. Thomas (Eds), Handbook of Perception and Human Performance (pp. 43.1-43.39). New York: Wiley.

Perlmuter, L., & Monty, R. (1973). The effect of choice of stimulus on paired-associate learning. Journal of Experimental Psychology, 99, 120-123.

Perlmuter, L., & Monty, R. (1977). The importance of perceived control: fact or fantasy? American Scientist, 65, 759-765.

Perlmuter, L., & Monty, R. (1982). Contextual effects on learning and memory. Bulletin of the Psychonomic Society, 20, 290-292.

Porubcansky, C. A. (1985). Speech technology: present and future applications in the airborne environment. Aviation, Space, and Environmental Medicine, 56, 138-143.

Roscoe, S. (1987). The trouble with virtual images revisited. Human Factors Society Bulletin, 30(11), 3-5.

Seilheimer, S. (1988). Current state of decision support system and expert system technology. Journal of Systems Management, 8, 14-19.

Senders, J. (1988). [The study of human error.] Unpublished manuscript.

Simon, H. (1978). Rationality as process and as product of thought. American Economics Review, 68, 1-16.

Slovic, P., Fischoff, B., & Lichtenstein, S. (1977). Behavioral decision theory. Annual Review of Psychology, 28, 1-39.

Snell, D. (1988). The evolution of a decision support system for airland battle targeting and intelligence (The ITDSS). Proceedings of the Sixth Annual Workshop on Command and Control Decision Aiding (pp. C27-C48). San Diego, CA: Naval Ocean Systems Center.

Steeb, R., & Johnston, S. (1981). A computer-based interactive system for group decision making. IEEE Transactions on Systems, Man, & Cybernetics, 11, 544-552.

Taylor, J. W., & Munson, K. (1977). History of Aviation. New York: Crown Publishers, Inc.

Tolcott, M., & Holt, V. (Eds.) (1987). Impact and Potential of Decision Research on Decision Aiding. (Dept. of the Navy Grant No. N00014-87-G-0146). Washington, DC: American Psychological Association. (DTIC No. AD-A192 276).

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and Biases. Science, 185, 1124-1131.

Ulvila, J., & Thompson, B. (1988). A computerized risk analysis aid. Computers and Operations Research, 15, 123-134.

Walrath, J. (1989). Integrating aircraft attitude and relative altitude information in a computer-generated symbolic display (Doctoral dissertation, University of South Dakota, 1988). Dissertation Abstracts International, 49, 4586B.

Wiener, E. (1988). Cockpit automation. In E. Wiener, and D. Nagel (Eds.), Human Factors in Aviation (pp. 433-461). New York: Academic Press, Inc.

Wiener, E., & Curry, R. (1980). Flight-deck automation: promises and problems. Ergonomics, 10, 995-1011.

Wickens, C. (1984). Engineering Psychology and Human Performance. Columbus, OH: Charles E. Merrill Publishing Co.

Woods, D. (1984). Visual momentum: A concept to improve the cognitive coupling of person and computer. International Journal of Man-Machine Studies, 21, 229-244.

Woods, D. (1986). Paradigms for intelligent decision support. In E. Hollnagel, G. Mancini, and D. Woods (Eds.), Intelligent Decision Support in Process Environments (pp. 153-173). New York: Springer-Verlag

Wright, P. (1974). The harassed decision maker: Time pressures, distractions, and the use of evidence. Journal of Applied Psychology, 59, 555-561.

BIBLIOGRAPHY

Frieze, I., & Weiner, B. (1971). Cue utilization and attributional judgment for success and failure. Journal of Personality, 39, 591-605.

Robertson, L., & Delis, D. (1986). Part-whole processing in unilateral brain damaged patients: dysfunction of hiearchical organization. Neuropsychology, 24, 363-370.

Seligman, M. (1975). Helplessness: On depression, development and death. San Francisco: W. H. Freeman.

von Neumann, J., & Morgenstern, O. (1944). Theory of Games and Economic Behavior. Princeton, NJ: Princeton University Press.